Field Test Program to Develop Comprehensive Design, Operating and Cost Data for Mercury Control Systems on Non-Scrubbed Coal-Fired Boilers

Quarterly Technical Report
Reporting Period: April – June 2001

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DISCLAIMER

ABSTRACT

With the Nation's coal-burning utilities facing the possibility of tighter controls on mercury pollutants, the U.S. Department of Energy is funding projects that could offer power plant operators better ways to reduce these emissions at much lower costs.

Mercury is known to have toxic effects on the nervous system of humans and wildlife. Although it exists only in trace amounts in coal, mercury is released when coal burns and can accumulate on land and in water. In water, bacteria transform the metal into methylmercury, the most hazardous form of the metal. Methylmercury can collect in fish and marine mammals in concentrations hundreds of thousands times higher than the levels in surrounding waters.

One of the goals of DOE is to develop technologies by 2005 that will be capable of cutting mercury emissions 50 to 70 percent at well under one-half of today's costs. ADA Environmental Solutions (ADA-ES) is managing a project to test mercury control technologies at full scale at four different power plants from 2000 – 2003. The ADA-ES project is focused on those power plants that are not equipped with wet flue gas desulfurization systems.

ADA-ES will develop a portable system that will be moved to four different utility power plants for field testing. Each of the plants is equipped with either electrostatic precipitators or fabric filters to remove solid particles from the plant's flue gas.

ADA-ES's technology will inject a dry sorbent, such as fly ash or activated carbon, that removes the mercury and makes it more susceptible to capture by the particulate control devices. A fine water mist may be sprayed into the flue gas to cool its temperature to the range where the dry sorbent is most effective.

PG&E National Energy Group is providing two test sites that fire bituminous coals and are both equipped with electrostatic precipitators and carbon/ash separation systems. Wisconsin Electric Power Company is providing a third test site that burns Powder River Basin (PRB) coal and has an electrostatic precipitator for particulate control. Alabama Power Company will host a fourth test at its Plant Gaston, which is equipped with a hot-side electrostatic precipitator and a downstream fabric filter.

During the third reporting quarter, progress was made on the project in the following areas:

Alabama Power Company Plant Gaston

- Long-term testing was completed at Plant Gaston.
- Economic analysis and topical report tasks were initiated.
- A technical paper on the Plant Gaston work was prepared for presentation at the MEGA Symposium/AWMA Mercury Specialty Conference.

Wisconsin Electric Power Company Pleasant Prairie Power Plant

- Sorbent screening testing was completed.
- Site preparation work continued for the testing to begin in Fall 2001.
- A technical poster paper on the Pleasant Prairie Power Plant work was prepared for presentation at the MEGA Symposium/AWMA Mercury Specialty Conference.

PG&E NEG Salem Harbor Station

- A review meeting was held at the site to discuss prebaseline test results.
- Coal and ash samples continued to be tested and analyzed.
- A technical poster paper on the Salem Harbor work was prepared for presentation at the MEGA Symposium/AWMA Mercury Specialty Conference.

PG&E NEG Brayton Point Station

- Prebaseline testing was conducted.
- Coal and ash samples continued to be tested and analyzed.

Technology Transfer

- Two technical papers were presented at the June AWMA conference.
- A presentation was made for a Western Coal Conference meeting April 24-26.
- A presentation was made for the ICAC annual meeting, May 3-5.

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LIST OF GRAPHICAL MATERIALS

There are no graphical materials included in this report.

EXECUTIVE SUMMARY

ADA-ES began work on a Cooperative Agreement with the Department of Energy in October, 2000 to demonstrate full-scale mercury control systems at coal-fired power plants. The project is the next step in the process of obtaining performance and cost data on full-scale utility plants for mercury control systems. Power generating companies that have entered into contracts with ADA-ES are PG&E National Energy Group, Wisconsin Electric Power Company and Alabama Power Company. During the three-year, $6.8 million project, integrated control systems will be installed and tested at four power plants. ADA-ES is responsible for managing the project including engineering, testing, economic analysis, and information dissemination functions.

On December 14, 2000 the Environmental Protection Agency (EPA) announced that it will be developing regulations for reducing emissions of mercury from coal-fired power plants. Proposed regulations are expected to be released by December, 2003 and the rules are scheduled to be finalized by December, 2004. It is expected that EPA will include the findings from the ADA-ES/DOE project in its analysis for establishing a mercury control regulation. DOE estimates that the cost to control these emissions will be $2-$5 billion annually.

The field test phase of the project began at Alabama Power Company's Plant Gaston during the second reporting quarter. Testing at this site was completed in the third reporting quarter. Sorbent screening testing was completed at Wisconsin Electric's Pleasant Prairie Power Plant during the quarter and the site continued preparations to accommodate field testing scheduled for the fall of 2001. Prebaseline testing was done at PG&E NEG's Brayton Point Station during the quarter and plans were made to visit the site to scope out modification that will be needed to install testing equipment. A meeting was held at PG&E NEG's Salem Harbor Station to review prebaseline test results. A number of technology transfer activities took place including presenting papers on the project at the annual AWMA meeting (June 2001), presenting a technical paper at a Western Coal Council meeting (April 2001), presenting a paper at the annual ICAC meeting (May 2001), and providing project information to NESCAUM.

INTRODUCTION

Cooperative Agreement No. DE-FC26-00NT41005 was awarded to ADA-ES to demonstrate mercury control technologies on non-scrubbed coal-fired boilers. Under the contract, ADA-ES will work in partnership with PG&E National Energy Group, Wisconsin Electric Power Company, Alabama Power, and EPRI to design and engineer systems to maximize effectiveness and minimize costs to curtail mercury emissions from power plant flue gases. Reports estimate that mercury control could cost the industry from $2 to $5 billion per year. Much of these costs will be associated with power plants that do not have wet scrubbers as part of their air pollution control configurations. The four plants that will be evaluated during the ADA-ES program are typical of this type of application which is found at 75% of the nearly 1100 units that would be impacted by new regulations.

Detailed topical reports will be prepared for each site that is tested under the program. Quarterly reports will be used to provide project overviews and technology transfer information.

EXPERIMENTAL

Field work was conducted on the project during the third reporting quarter at Plant Gaston and Brayton Point. Site modifications continued at Pleasant Prairie Power Plant and equipment fabrication began (spray cooling and activated carbon injection systems). Detailed results of the testing at each power plant will be provided in separate topical reports.

Technology Transfer

Technology transfer activities continued during the third reporting quarter of the project. Reference citations of the formal presentations are provided below:

Durham, M.D., C.J. Bustard, R. Schlager, C. Martin, S. Johnson and S. Renninger (2001). "Field Test Program to Develop Comprehensive Design, Operating and Cost Data for Mercury Control Systems on Non-Scrubbed Coal-Fired Boilers", presented at the 2001 A&WMA Annual Meeting, Paper No. 24, Orlando, FL, June 24-28.

Sjostrom, S., J. Bustard, M. Durham and R. Chang (2001). "Mercury Removal Trends in Full-Scale ESPs and Fabric Filters," presented at the 2001 A&WMA Annual Meeting, Paper No. 471, Orlando, FL, June 24-28.

Schlager, R.J. (2001). "Mercury and the Future of Coal," presented at the Denver Coal Club, Denver, CO, May 10.

Durham, M.D. (2001). "Mercury Control for Coal-Fired Boilers," presented at the ICAC Annual Meeting, Dorado, Puerto Rico, May 3.

Bustard, C.J. (2001). "Mercury Control for Coal-Fired Boilers," presented at Burning PRB Coal: Risk Management Strategies and Tactics, Western Coal Council, Birmingham, Alabama, April 25.

In addition to the above papers and presentations, information on the project was sent to Dr. Praveen Amar of NESCAUM for a meeting in Canada in early June. Dr. Praveen's contact information is:

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Director, Science and Policy
NESCAUM
129 Portland Street
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Attachment B contains copies of the formal technical papers presented at the A&WMA Annual Meeting.

RESULTS AND DISCUSSION

Field testing was conducted at two sites during the third reporting quarter. Site work continued at the Pleasant Prairie Power Plant in preparation for field testing later in 2001. Initial work continued at the PG&E NEG sites in preparation for testing during 2002. Detailed results of the testing at each power plant will be provided in separate topical reports.

CONCLUSION

Work began on Cooperative Agreement No. DE-FC26-00NT41005 in October 2000. Initial activities include holding a project kickoff meeting, securing the fourth test site (Alabama Power Company Plant Gaston), and performing various planning and administrative functions. Field testing began during the second reporting period, and test planning for the remaining sites began. Test work was completed at the Gaston site during the third reporting period. Site preparations are underway at the Wisconsin Electric site for testing to begin during the fourth reporting period. Technology transfer activities are progressing at a rapid pace. Interest in participating in the project by third parties (sorbent developers/suppliers and power generating companies) is growing.

REFERENCES

LIST OF ACRONYMS AND ABBREVIATIONS

AWMA	Air & Waste Management Association
DOE	Department of Energy
EPA	Environmental Protection Agency
ESP	Electrostatic Precipitator
ICAC Companies	Institute of Clean Air
NESCAUM	Northeast States for Coordinated Air Use Management
PRB	Powder River Basin
QA/QC	Quality Assurance/Quality Control
WEPCO	Wisconsin Electric Power Co.

ATTACHMENT A

Accomplishments and Status Assessment
April 1 – June 30, 2001

General

- The project is continuing to get requests from sorbent developers and suppliers to test their materials as part of the DOE program. A new arrangement has been set up where the third parties will pay for the cost of the additional testing by URS
- Several organizations have expressed an interest in joining the project team. ADA-ES is in discussions with these organizations to ascertain their objectives and funding targets for their participation.
- A team meeting is being planned for the afternoon of 8/20/01 at the Mercury/MEGA conference.

Alabama Power Company Plant Gaston

- The final QA/QC plan for the long-term testing was prepared and distributed.
- The long-term testing series was performed in April, 2001.
- Southern Research Institute performed Ontario Hydro stack testing and several additional tests at the inlet to the ESP.
- EPA personnel were on site on April 25 to audit the testing.
- The test facility at Gaston was decommissioned and removed during May.
- Coal and ash samples have been sent for analysis.
- Work has begun on the costs associated with implementing mercury controls based on the Gaston testing.
- The topical report for the Gaston testing was started.

Wisconsin Electric Power Company Pleasant Prairie Power Plant

- Site visit made during the quarter to finalize equipment layout and work scope split.
- A draft version of the Contractor Work Package was prepared.
- The test matrix for the sorbent screening tests was revised and finalized. Sorbent screening tests were performed by URS. In addition to the normal suite of materials, SorbTech, Westvaco, EPA and WEPCO provided sorbents for evaluation.
- Working with Mostardi Platt for the source testing phase of the P4 work. Discussions include looking at measuring total particulate emissions and measuring the emissions of fine carbon fractions.
- Draft test plan being prepared for the parametric test series.
- The test plan for the prebaseline and screening testing was prepared and reviewed.

PG&E NEG Salem Harbor Station

- A briefing meeting was held at Salem Harbor on June 1, 2001 to review prebaseline test results.
- Analysis of coal, precipitator ash and fly ash have been performed and results have been reviewed and analyzed.
- Request submitted to collect coal and ash samples in July when state-required mercury testing will occur at Salem Harbor.

PG&E NEG Brayton Point Station

- A briefing meeting was held with PG&E NEG during the week of May 29, 2001 at Brayton Point.
- Prebaseline testing plan prepared.
- Prebaseline testing was conducted at Brayton Point during the week of June 18, 2001.
- Plans were made to visit Brayton Point in July to scope out ductwork, port locations, equipment locations and platform needs.

Status Assessment

- Alabama Power Company's Plant Gaston: This facility was the first to be tested in the program. Prebaseline testing was completed in February, 2001 and the parametric test series was performed in March, 2001. The long-term test series was completed during April, 2001. The test facility was decommissioned during May. Economic analysis and topical report were started in June.

- WEPCO Pleasant Prairie Power Plant: Sorbent screening testing was completed at Pleasant Prairie in June, 2001. Equipment is scheduled to be on site by the end of July 2001. Equipment installations are scheduled to begin in August, 2001, with parametric and long-term testing is scheduled through November, 2001.

- PG&E NEG Salem Harbor Station: Prebaseline measurements were made at Salem Harbor during February. Mercury emissions measurements will be made at the station during July 2001 as required by the state of Massachusetts. The project team will coordinate coal and ash samples during the state testing. Additional prebaseline testing, parametric and long-term testing of Salem Harbor is scheduled for Spring, 2002. Ash samples are being analyzed by Microbeam Technologies and results are being evaluated.

- PG&E NEG Brayton Point Station: Prebaseline testing was performed at Brayton Point during June 2001. Mercury emissions measurements will be made at the station during the summer of 2001 as required by the state of Massachusetts. The site will be visited in July 2001 to evaluate the ductwork, port locations, equipment locations and platform needs. Parametric and long-term testing of Brayton Point is scheduled for Fall, 2002.

- Technology Transfer: Presentation on the project were made at a Western Coal Council meeting (April 2001), ICAC Annual Meeting (May 2001) and at a meeting of the Denver Coal Club (May 2001). Two technical papers on the project were presented at the AWMA annual meeting in June 2001. Additional papers were prepared for presentation at the MEGA Symposium and Mercury Specialty Conference in August 2001. WEPCO has scheduled an open house at the Pleasant Prairie Power Plant during the MEGA Symposium. Additional papers and presentations have been committed for the A&WMA EM Journal (July 2001), PRB Coal Conference (Gillette, WY, August 15-16, 2001), U.S./China Clean Energy Technology Forum (Beijing, China, August 29-31, 2001), and the DOE Clean Coal and Power Conference (Washington, DC, November 19-20, 2001).

ATTACHMENT B

Technical Papers

"Field Test Program to Develop Comprehensive Design, Operating and Cost Data for Mercury Control Systems on Non-Scrubbed Coal-Fired Boilers"

PAPER # 24

Michael D. Durham, Ph.D., C. Jean Bustard, Richard Schlager, Cameron Martin, and Stephen Johnson
ADA-ES; 8100 SouthPark Way, B-2; Littleton, CO 80104; (303) 734-1727

Scott Renninger, US Department of Energy, National Energy Technology Laboratory

ABSTRACT

This paper describes a DOE/NETL program being conducted by ADA-ES that represents the U.S. government's first step toward defining technology platforms for power generating companies to use in meeting new mercury regulations. The Environmental Protection Agency (EPA) announced on Dec. 14, 2000 that they would develop regulations to reduce the emissions of mercury from coal-fired power plants.

Under the contract, ADA-ES will work in partnership with PG&E National Energy Group, Wisconsin Electric Power Company, Alabama Power, and EPRI to design and engineer systems to maximize effectiveness and minimize costs to curtail mercury emissions from power plant flue gases. Reports estimate that mercury control could cost the industry from $2 to $5 billion per year. Much of these costs will be associated with power plants that do not have wet scrubbers as part of their air pollution control configurations. The four plants that will be evaluated during the ADA-ES program are typical of this type of application which is found at 75% of the nearly 1100 units that would be impacted by new regulations.

INTRODUCTION

On December 14, 2000 the Environmental Protection Agency announced that they plan to develop regulations to reduce mercury emissions from coal-fired utility boilers. This decision is based on growing health effects concerns over current levels and potential buildups of methylmercury in lakes and rivers. Methylmercury is capable of bioaccumulation resulting in higher levels in game fish. Mercury is a neurotoxin that impacts rapidly developing cells, so that the greatest risks of exposure are the fetuses of pregnant women who consume fish with elevated levels of mercury. The levels currently being found in lakes in several areas of the country are sufficiently high that state health agencies are issuing advisories to restrict fish consumption.

Over the past ten years, much effort has been directed at reducing the use of mercury in consumer products. In addition, new emission control technologies have been implemented on medical waste and municipal waste incinerators. As a result, coal-fired electric generators now represent the largest single source of anthropogenic mercury emissions in the US.

In anticipation of potential regulations, a great deal of research has been conducted during the past decade to characterize the emissions and control of mercury compounds from the combustion of coal. Much of this research was the result of funding from the Department of Energy, EPA, and EPRI and are summarized in the comprehensive AWMA Critical Review Article (Brown et al., 1999).

PROGRAM OBJECTIVES

With regulations rapidly approaching, it is important to concentrate the development effort on the most mature control technologies. Injection of dry sorbents such as activated carbon into the flue gas and further collection of the sorbent by conventional particulate control devices, electrostatic precipitators (ESPs) and fabric filters, represents the most mature and potentially most cost-effective control technology for power companies. However, all of the work to date has been limited to bench-scale and pilot experiments (Haythornthwaite et al., 1997; Sjostrom et al., 1997). Although these reduced-scale programs provide valuable insight into many important issues, they cannot fully account for impacts of additional control technology on plant-wide equipment. For example, it has been possible to measure high mercury capture at relatively low temperatures in small pilot systems for relatively short periods. However, these lower temperatures may not be practically achieved in a full-scale system continuously without deposition and corrosion in cold spots of ducting and particulate control equipment.

Therefore, it is necessary to scale up the technology and perform full-scale field tests to document actual performance levels and determine accurate cost information. The objectives of this program are to:

- accelerate the scale-up and availability of commercial mercury control systems for coal-fired plants;
- obtain data on operability, maintainability, and reliability;
- determine maximum mercury removal for various plant configurations; and
- determine the total costs associated with mercury control as a function of fuel and plant characteristics.

This multifaceted field-test program will provide critical data that will be used by many different groups. It will provide EPA with accurate information on the levels of control that can be reasonably attained for different plants. It will complement the emission inventory data obtained during the 1999 ICR data collection effort. Cost and operating data will provide power-generating companies with the means to estimate costs for various plants to perform strategic planning on a system-wide basis. The economic analysis will include:

- Capital costs;
- Sorbent usage costs;
- Impact on operation of particulate control equipment;

- Balance of plant;
- Waste disposal and byproduct utilization issues;
- Enhancements, such as cooling; and
- O&M requirements.

TEAM MEMBERS

ADA-ES has assembled a program team consisting of technical leaders in the areas of mercury measurement, transformations during coal combustion, capture by existing emission-control equipment as well as the design of integrated emission-control systems. Qualifications of individual team members were built by performing pioneering mercury control work in the U.S. over the past decade. Organizations represented on the team include URS Radian, Physical Sciences, Apogee Scientific, EPRI, Energy & Environmental Strategies, EnviroCare, Microbeam Technologies, EERC, Environmental Elements Corp., Consol, Hamon Research Cottrell, and NORIT Americas.

TEST SITES

This program is directed at providing sufficient data to determine costs and capabilities for plants that do not have flue gas desulfurization (FGD) systems. This group represents not only the largest proportion of coal-fired power generators (83% by number or 75% by generation capacity), it also represents the most difficult application for mercury control.

To gather data on the application of sorbent injection for removal of mercury from coal combustion flue gas that can be used for as many plants as possible, sites were selected to take into account factors related to the fuel characteristics, the operating conditions of the unit, and interactions with other air pollution control devices. Sites that burn both Eastern bituminous and Western subbituminous coals were included because of differences in speciation of mercury in the flue gas, which greatly affects the efficiency of mercury removal in air pollution control devices. Measurements of the concentration of mercury species taken in the stacks of pilot and full-scale coal combustion systems reported anywhere from 10% Hg^0 to 95% Hg^0 upstream of the air pollution control device (APCD) (Brown et al., 1999). Oxidized mercury, particularly when present as $HgCl_2$, is far easier to capture than is mercury in elemental (Hg^0) form.

In addition to differences in the forms of mercury produced by different coals, the fly ash produced by bituminous and subbituminous coals result in different mercury capture characteristics. For example subbituminous ashes produce higher absorption rates of mercury at higher temperatures and lower LOI values than do ashes from bituminous coals.

There are other important differences between the flue gas produced by Eastern and Western coals. For Eastern bituminous coals a small proportion, 2 to 3%, of the SO_2 is converted to sulfur trioxide (SO_3). SO_3 is important because it reacts with the water vapor to form sulfuric acid. The gas stream for a low-sulfur eastern coal will have sufficient SO_3 that sulfuric acid will begin to condense at 270^{o}F. This means that the gas stream cannot be cooled for enhancement of mercury capture without first eliminating the SO_3 or else severe corrosion of ducting and ESP components would be expected. On the other hand, the higher alkali content of a Western subbituminous coal neutralizes all of the SO_3 resulting in a dew point of 120°F. This means that a flue gas cooling system could be operated without sulfuric acid corrosion. If an SO_3 injection system is used to control particle resistivity in the ESP, its operation must be integrated with the gas cooling system to provide both resistivity control without causing corrosion problems.

Although fabric filters represent only 10% of the current power plant applications, they are an important part of the program because the number of fabric filters could increase significantly as a result of mercury control regulations. If a high level of mercury removal is mandated, a baghouse may be the most economical choice. Meserole (1999) predicts that achieving 80% removal at a plant with an ESP would require 10 times the amount of sorbent as that required if a fabric filter were installed. The difference in the cost of the additional sorbent would be greater than the annualized cost of a new fabric filter.

Figure 1 shows a plot of the distribution of the specific collection areas (SCA) of ESPs for coal-fired boilers. This shows that there is a large number of smaller ESPs (i.e. < 250 ft^2/kacfm) that would have difficulty handling the additional burden of collecting injected sorbent. Therefore, we decided to include a COHPAC baghouse in the test program because COHPAC represents a cost-effective retrofit option for power plants with ESPs. COHPAC is an EPRI-patented concept that places a high air-to-cloth ratio baghouse downstream of an existing ESP to improve overall particulate collection efficiency. Dry sorbents can be injected upstream of COHPAC, downstream of the ESP. The advantages of this configuration are:

- Sorbents are mixed with a small fraction of the ash (nominally 1%) which reduces the impact on ash reuse and waste disposal.
- Sorbent requirements are reduced by a factor of ten relative to the existing ESP
- Capital costs for COHPAC are less than other options such as replacing the ESP with a baghouse or larger ESP.

Table 1 shows a summary of the four power plants that are participating in the field test program. These four plants provide a means to document the performance of mercury control technology for both subbituminous Powder River Basin (PRB) coals and low-sulfur bituminous coals. Three of the plants have ESPs while the fourth plant has both a hot-side ESP and a COHPAC baghouse. This table also presents the expected timing for the four full-scale tests. This schedule was set up to avoid testing either during the summer peak generation season and harsh winter conditions. Table 2 presents data on mercury emissions from three of the four plants as determined during the ICR testing. Additional details on the four plants are provided below.

Figure 1. Population Density of ESPs as a Function of SCAs.

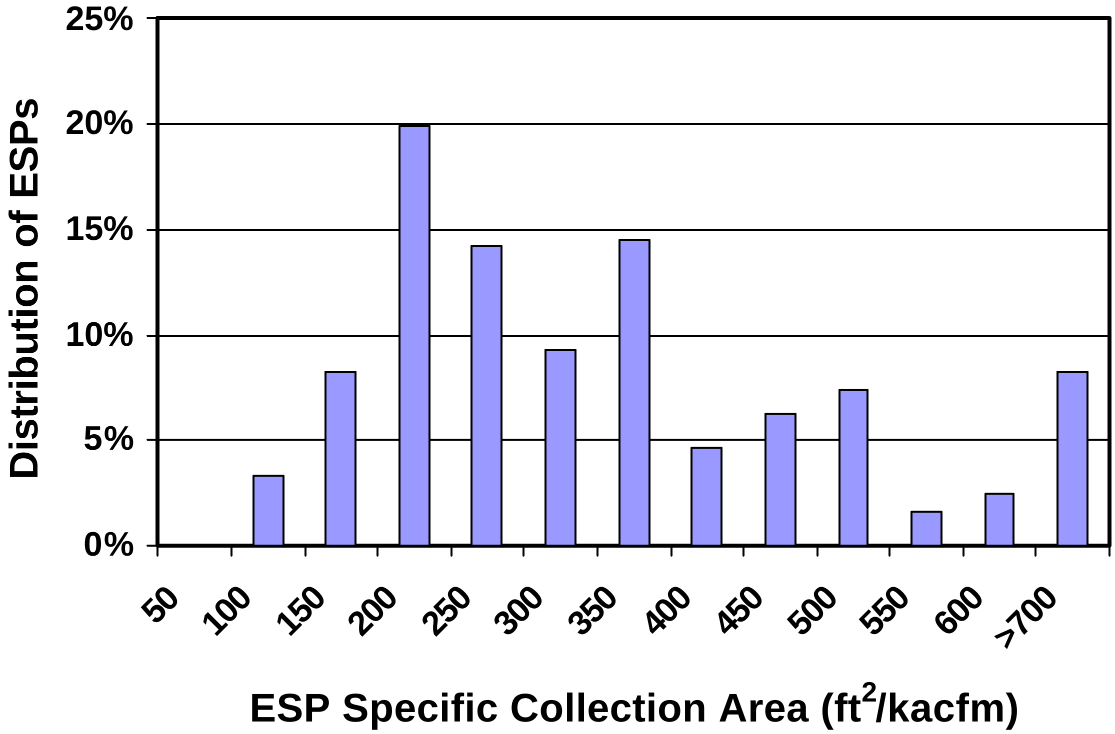


Table 1. Host site for the Mercury Control Field Test Program

Test Site	**Coal**	**Particulate Control**	**Field Test Schedule**
Alabama Power Gaston	Low S. Bituminous	Hot Side ESP COHPAC FF	Spring 2001
Wisconsin Electric Pleasant Prairie	PRB	Cold Side ESP	Fall 2001
PG&E NEG Salem Harbor	Low S. Bituminous	Cold Side ESP	Spring 2002
PG&E NEG Brayton Point	Low S. Bituminous	Cold Side ESP	Fall 2002

Table 2. Mercury Emissions Data on Three Host Sites.

Plant and Unit Sampling Location	Particle Bound	Oxidized, Hg^{2+}	Elemental, Hg^0	Total, Hg
Brayton Point U3				
Inlet (µg/dscm)	1.58	2.53	1.18	5.3
Outlet (µg/dscm)	0.39	2.09	1.19	3.67
Removal Efficiency (%)	76.46	-16.93	-3.25	31.92
Salem Harbor U3				
Inlet (µg/dscm)	2.83	0.10	0.29	3.22
Outlet (µg/dscm)	0.0554	0.0925	0.2501	0.3980
Removal Efficiency (%)	97.96	-23.07	8.39	87.28
Gaston U1[a]				
Inlet (µg/dscm)	2.26	1.72	2.81	6.80
Outlet (µg/dscm)	0.60	3.99	2.06	6.65
Removal Efficiency (%)	73.45	--131.98	26.69	2.21

a. Measurements made across hot-side ESP not COHPAC baghouse.

Alabama Power E.C. Gaston Unit 3 is a 270 MW B&W wall-fired boiler that burns a washed Alabama bituminous coal. The coal has a heating value of 13,700 BTU/lb and a mercury content of 0.06 µg/g and 0.03% chlorine. Particulate is captured by a Research Cottrell hot-side weighted-wire ESP with an SCA of 274 ft^2/kacfm. This is followed by a Hamon Research Cottrell COHPAC baghouse designed with an air-to-cloth ratio of 8.5:1 gross. The temperature of the baghouse ranges from 240-300 ^oF. During the test program the sorbent will be injected downstream of the ESP and air preheater and upstream of the baghouse.

Wisconsin Electric Pleasant Prairie Power Plant Unit 2 is a 600 MW Riley Stoker balanced draft, turbo-fired boiler that burns PRB coal. The coal has a heating value of 11,897 BTU/lb with mercury content of 0.1 µg/g and 0.0015% chlorine. Particulate is captured by a Research Cottrell cold-side weighted wire ESP with an SCA of 468 ft^2/kacfm. A WAHLCO SO_3 system is used to condition the flyash. The unit operates in a temperature range of 280-310 ^oF.

PG&E National Energy Group (NEG) Salem Harbor Unit 1 is an 85 MW B&W Radiant boiler that fires a South American bituminous coal. The coal has a heating value of 11,300 BTU/lb with mercury content of 0.03µg/g and 0.03% chlorine. Particulate is captured by an Environmental Elements cold-side rigid-electrode ESP with an SCA of 474 ft^2/kacfm. A FuelTech urea-based SNCR system is used to control NO_x levels. The ESP operates at temperatures as low as 250 ^oF.

PG&E NEG Brayton Point Unit 1 is a 250 MW CE tangential, twin furnace boiler burning a low-sulfur eastern bituminous coal. The coal has a heating value of 12,319 BTU/lb with mercury content of 0.05 µg/g and 0.08% chlorine. A pair of ESPs in series captures particulate. The first is a Koppers weighted-wire cold-side ESP with an SCA of 156 ft^2/kacfm. The second unit is a Research Cottrell rigid-electrode ESP with an SCA of 403 ft^2/kacfm. An EPRICON

SO_3 system is used to condition the flyash. The plant uses Separations Technology equipment to process the collected flyash by electrostatically separating LOI carbon from the flyash (Giovando, 2000).

SORBENT SELECTION AND SCREENING

The test program at each site allows for the evaluation of two sorbents including a lignite-derived activated carbon supplied by NORIT, referred to as Darco FGD carbon, and one alternative sorbent. FGD is considered the benchmark for these tests because of its wide use in DOE/EPRI/EPA sponsored testing. Because of the economic impact of sorbent cost on the overall cost of mercury control, it is desirable to find less expensive sorbents such as flyash-derived products or a less expensive form of activated carbon. A sorbent selection criteria has been developed so that sorbent vendors/developers can clearly understand the needs and requirements of this program. In summary an alternative sorbent must:

- Be at least 25% less expensive than FGD carbon;
- Be available in quantities of at least 15,000 lbs, and potentially as high as 250,000 lbs. for site tests;
- Be available in sufficient quantities to supply at least 100,000 tons per year by 2007; and
- Have a capacity of at least 100 μg/g as measured in the laboratory by URS Corporation.

Sorbents will be tested on a slipstream of flue gas for site-specific mercury capacity using URS Corporations' fixed bed mercury absorption device. This device was developed with funding from EPRI and has been used to screen dozens of sorbents. Adsorption tests are conducted by saturating sorbents with either elemental mercury or mercuric chloride in the presence of simulated flue gas. The test apparatus is illustrated in Figure 2. In the laboratory, simulated flue gas is prepared by mixing heated nitrogen gas streams containing SO_2, HCl, NO_x, CO_2, H_2O, and O_2. Mercury is injected into the gas by contacting nitrogen carrier gas with either recrystallized mercuric chloride solids or with an elemental mercury permeation tube (VICI Metronics) housed in a mercury diffusion vessel. Mercury concentration is controlled by the temperature of the diffusion vessel and the nitrogen carrier gas flow rate. During field screening tests, actual flue gas is drawn into the apparatus.

Sorbents are mixed in a sand diluent prior to being packed in a temperature-controlled, adsorption column (1.27 cm ID). A ratio of 20 mg sorbent to 10 g of sand is generally used for carbon-based sorbents and zeolites, and 200 mg sorbent to 10 g of sand was used for fly ashes. These mass-loadings are chosen to achieve reasonable mercury breakthrough times with the respective sorbents. Prior to flue gas exposure, the sorbent fixed-bed is heated to the desired temperature for periods up to one hour. During this time, the flue gas is by-passed directly to the analytical system to determine the "inlet" mercury concentration. Adsorption tests were initiated by flowing flue gas downward through the fixed-bed column at a flow rate near 1 L/min. Mercury measurements are made with a mercury semi-continuous emissions analyzer (S-CEM) described later in this section.

The amount of mercury exiting the sorbent column is measured on a semi-continuous basis. Gas is passed through the column until 100% of the inlet mercury is detected at the outlet (100% breakthrough). The 100% breakthrough (equilibrium) capacity of the sorbent (µg Hg/g sorbent) is determined by summing the total mercury adsorbed until the time when the outlet mercury concentration is first equal to the inlet concentration.

SEMI-CONTINUOUS EMISSIONS MONITOR

Semi-continuous gaseous mercury analyzers built by Apogee Scientific will be used during this program to provide near real-time feedback during baseline, parametric and long-term testing. Continuous measurement of mercury at the inlet and outlet of the particulate collector is considered a critical component of a field mercury control program where mercury levels fluctuate with boiler operation (temperature, load, etc.) and decisions must be made concerning parameters such as sorbent feed rate and cooling. The analyzers that will be used for this program consist of a commercially available cold vapor atomic absorption spectrometer (CVAAS) coupled with a gold amalgamation system (Au-CVAAS). A sketch of the system is shown in Figure 3. One analyzer will be placed at the inlet of the particulate collector and one at the outlet of the particulate collector during this test program.

Although it is very difficult to transport non-elemental mercury in sampling lines, elemental mercury can be transported without significant problems. Since the Au-CVAAS measures mercury by using the distinct lines of UV absorption characteristic of elemental Hg (Hg^0), the non-elemental fraction is either converted to elemental mercury (for total mercury measurement) or removed (for measurement of the elemental fraction) near the sample extraction point. This minimizes any losses due to the sampling system.

For total vapor-phase mercury measurements, all non-elemental vapor-phase mercury in the flue gas must be converted to elemental mercury. A reduction solution of stannous chloride in hydrochloric acid is used to convert Hg^{2+} to Hg^0. The solution is mixed as prescribed in the draft Ontario Hydro Method for manual mercury measurements.

Figure 2. Bench –Scale, Fixed-Bed Mercury Adsorption

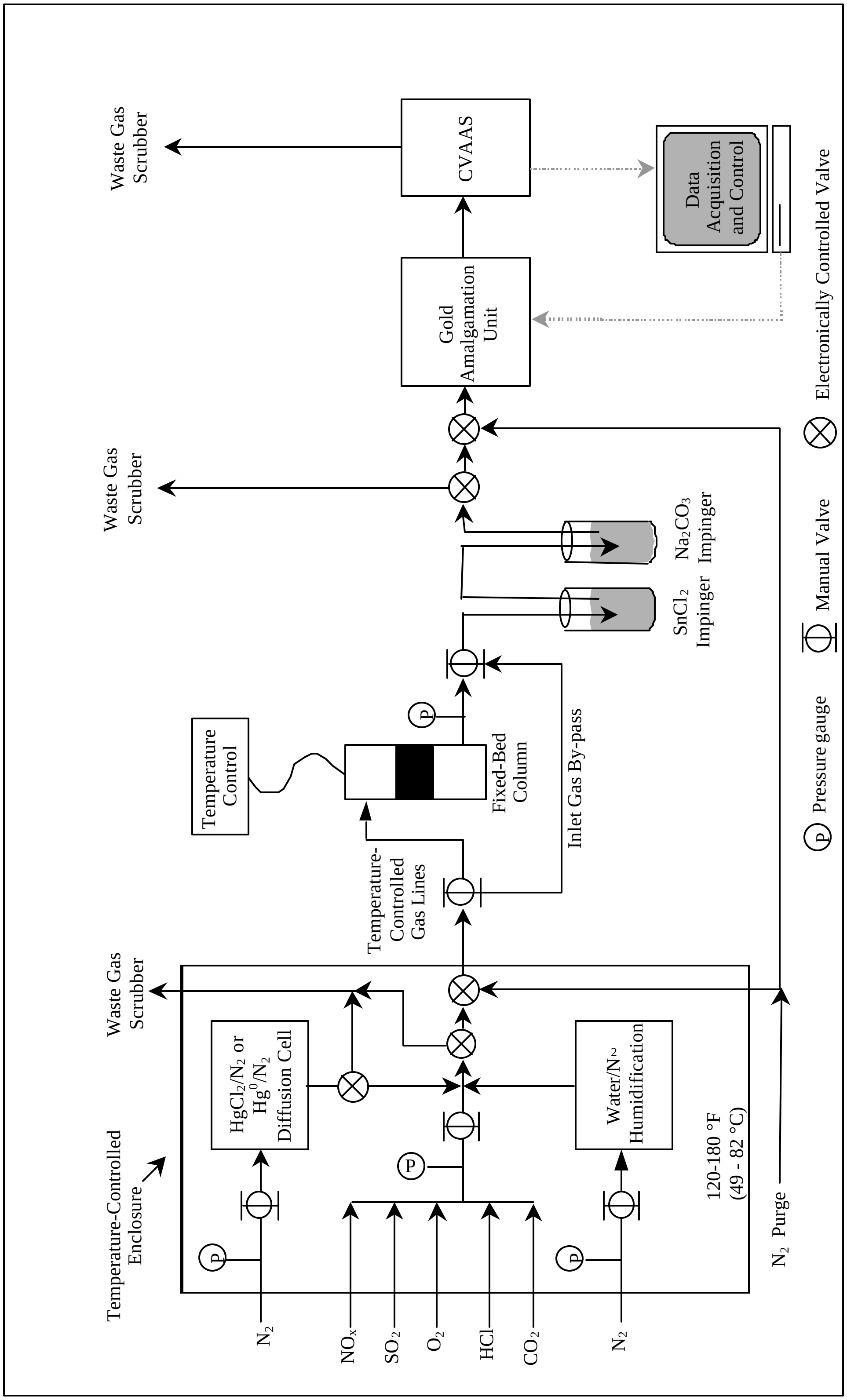
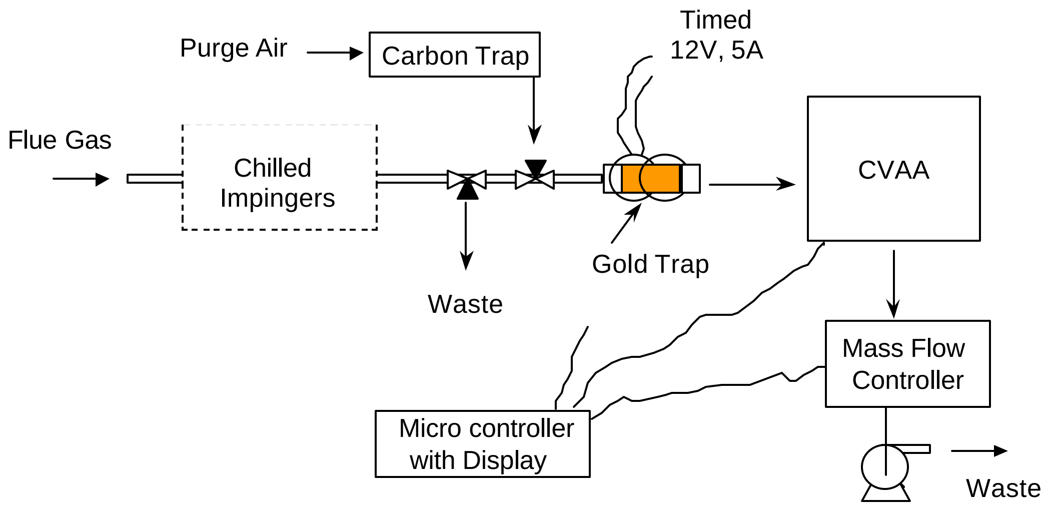


Figure 3. Sketch of Mercury Measurement System.



To measure speciated mercury, an impinger of potassium chloride (KCl) solution mixed as prescribed by the draft Ontario Hydro Method is placed upstream of the stannous chloride solution to capture oxidized mercury. Unique to this instrument is the ability to continuously refresh the impinger solutions to assure continuous exposure of the gas to active chemicals. The Au-CVAAS system is calibrated using elemental mercury vapor. The instrument is calibrated by injecting a metered volume of mercury-laden air from the air-space of a vial containing liquid mercury at a precisely measured temperature into the analyzer.

The Au-CVAAS can measure mercury over a wide range of concentrations. Since the detection limit of the analyzer is a function of only the quantity of mercury on the gold wire and not the concentration in the gas, the sampling time can be adjusted for different situations. Laboratory tests with stable permeation tube mercury sources and standard mercury solutions indicate that the noise level for this analyzer is 0.2 ng mercury. To sample at 50 – 100 times the noise level during field testing, the sampling time is set so at least 10 ng mercury is collected on the wire before desorption. Table 3 shows the sampling time required for different concentrations of mercury in the flue gas with 2 liters per minute sample flow.

Table 3. Sampling Time Required for Au-CVAA Analyzer.

VAPOR-PHASE MERCURY CONCENTRATION ($\mu g/M^3$)	MINIMUM SAMPLE TIME (MIN)	NOISE LEVEL ($\mu g/M^3$)
5	1	0.1
2.5	2	0.05
1	5	0.02
0.5	10	0.01

Particulate is separated from the gas sample using a self-cleaning inertial gas separation arrangement modified for use with this mercury analyzer under an EPRI mercury control program. This arrangement uses a system where excess sample flow continuously scours particulate from a secondary filter so as to minimize any mercury removal or conversion due to the presence of particulate.

SORBENT INJECTION EQUIPMENT

The sorbent injection equipment is a skid mounted, portable dilute phase pneumatic system. The activated carbon will be delivered to the plant in 900-lb supersacks, which will be stored on pallets adjacent to the injection skid. Operators will load individual supersacks onto the injection skid by a hoist. The reagent is metered by a variable speed screw feeder into an eductor that provides the motive force to carry the reagent to the injection point. A positive displacement blower provides the conveying air. A PLC system is used to control system operation and adjust injection rates. Flexible hose will carry the reagent from the feeder to a distribution manifold located upstream of the particulate collector feeding multiple injection probes inserted into the duct to distribute the sorbent evenly across the flue gas.

FIELD TESTING

Prior to installing injection equipment, preliminary system operation, performance and mercury level measurements will be made. Mercury will be measured using the S-CEM across the particulate control device. These measurements will be used to expedite the parametric evaluation and provide insight as to current mercury removal efficiencies during “normal” operation with varying boiler load. During this test, the S-CEM will be run continuously for a minimum of 24 hours at each site. These data will be used to design the parametric tests with the minimum number of uncontrolled variables.

After installation of the sorbent injection equipment, a second set of baseline tests will be conducted to fully document baseline conditions. During this test boiler load will be held steady at “full-load” conditions during testing hours, nominally 7:00 am to 7:00 p.m. Mercury levels across the particulate control device will be measured using two separate methods: 1) the S-CEM; and 2) standard Ontario Hydro Testing. This baseline test is expected to run for one week.

Following the baseline test, a parametric series of tests will be conducted to document mercury removal levels as a function of injection rate and gas temperature. The flue gas temperature will be lowered at each condition to document the effect of 10 - 20^{o}F decrease in temperature on mercury removal efficiencies. The maximum sorbent injection rate will be established by either a 90% mercury removal level or a sorbent feed proportional to 30 lb/Macf which is considered an economic maximum. The sorbent injection rates to achieve different removal rates will be set with feedback from the S-CEM.

The next series of parametric tests will be conducted using an alternative sorbent. Mercury removal as a function of injection rate will be measured at the optimum temperature measured during the previous test series. After this test the field crew will leave the site to analyze data and work with team members on establishing conditions for the long-term test.

The final test will be a mercury removal validation program conducted for a maximum of fourteen days at the "optimum" plant operating conditions (lowest cost/highest mercury removal) as determined from the parametric tests. The S-CEM will be used for continuous monitoring of mercury removal. Ontario Hydro measurements at the inlet and outlet will be conducted.

WASTE CHARACTERIZATION

During each field test program, samples of the ash/sorbent mixture from the hoppers will be collected and analyzed. The standard testing technique used for assessing hazardous waste characteristics is the Toxicity Characteristic Leaching Procedure (TCLP, SW846-1311). A 100-gram sample of ash is exposed to 1-liter of acidic solution (acetic acid-or acetate based) for 24 hours. The solution is then analyzed for several metals (including mercury) to determine how much of each target metal was leached from the solid sample. Results are compared against limits established by regulation. In the case of mercury, a maximum leachable level of 0.2 mg/liter has been established.

A second series of tests will be performed to answer the question of the stability of the mercury. The potential long-term environmental impact of the mercury-laden ash will be determined using two techniques, leaching and thermal desorption. The Energy and Environmental Research Center (EERC) will conduct these tests. Leaching tests are done using a method known as the synthetic groundwater leaching procedure (SGLP) (Hassett, et al., 1999). This test is modeled after the TCLP, but modified to allow for disposal scenarios. A shake extraction technique is used to mix the solid sample with an aqueous solution. Aliquots of the liquid are then analyzed after 18 hours, 2 weeks, and 4 weeks. Thermal desorption tests will be performed using a special test fixture that is heated using a programmable temperature controller. The temperature of the ash sample is ramped to 500 ^{o}C at a rate of 20 ^{o}C per minute. Mercury that is released by the sample is swept to a spectrophotometer for mercury measurement as a function of time and temperature.

DESIGN AND ECONOMICS OF SITE SPECIFIC CONTROL SYSTEM

After completion of testing and analysis of the field data, the requirements and costs for full-scale, permanent commercial implementation of the necessary equipment for mercury control using sorbent injection technology will be determined. Process equipment shall be sized and designed based on test results and the plant specific requirements (reagent storage capacity, plant arrangement, retrofit issues, winterization, controls interface, etc.). A conceptual design document shall be developed with drawings and equipment lists. Modifications to existing plant equipment shall be determined and a work scope document developed based on input from the plant which may include modifications to the particulate collector, ash handling system, compressed air supply, electric power capacity, other plant auxiliary equipment, utilities and other balance of plant engineering requirements. Reagent type and sources shall be evaluated to determine the most cost -effective reagent(s) for the site.

TECHNOLOGY TRANSFER

Transferring the information generated during this program to the coal-fired power generation industry will be an important part of the program. This will be accomplished through technical papers presented at various forums including AWMA annual meeting, ICAC meetings, AWMA Specialty Conferences on mercury, and the EPRI/DOE/EPA MEGA Symposium. In addition, results from the test programs will be made available to the public as soon as they are completed and approved by DOE and the host power generating companies. We will use the ADA-ES website (www.adaes.com) to distribute these reports.

ACKNOWLEDGEMENTS

This large-scale test program could not be conducted without technical and administrative support from a large number of people at the various power-generating companies. We would like to acknowledge all of these individuals and especially the following key personnel: Dr. Larry Monroe of Southern Company Services, Mr. Herb Stowe of PG&E NEG, and Mr. Dick Johnson of Wisconsin Electric. We also acknowledge the valuable input being provided by Dr. Ramsay Chang of EPRI and Mr. James Kilgroe of EPA.

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Mercury Removal Trends in Full-Scale ESPs and Fabric Filters

Abstract # 471

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ABSTRACT

In 1999 the Environmental Protection Agency initiated an Information Collection Request to gather data from coal-fired generation facilities to better assess the mercury levels processed (through burning coal), captured, and emitted from these facilities. All plants that provide more than 33% of their potential energy output and over 25 MW to any utility power distribution system for sale were required to report the mercury entering the system. A statistical sampling of these were identified for stack and waste measurements. These data, in conjunction with data collected on DOE and EPRI programs, provide insight into the overall mercury capture in the plants and the factors affecting the capture.

With regulations rapidly approaching, the need for full-scale evaluations to augment available data is necessary. Under a DOE/NETL cooperative agreement, ADA-ES is working in partnership with PG&E National Energy Group, Wisconsin Electric, a subsidiary of Wisconsin Energy Corp., Alabama Power Company, a subsidiary of Southern Company, Ontario Power Generation, and EPRI on a field evaluation program of sorbent injection upstream of existing particulate control devices for mercury control. Included in this program is a task to analyze available data to develop trends and factors influencing the trends for plants without scrubbers for SO_2 control, and ESPs or fabric filters as the particulate control equipment. Data considered include that provided by the ICR reports, including temperature, as well as ash LOI and flue gas conditioning, when available. Results from recent R&D work conducted by EPRI and results from the full-scale evaluations will also be incorporated.

This paper presents a summary of the initial analysis of the ICR data and results from DOE and EPRI programs.

INTRODUCTION

On December 14, 2000 the Environmental Protection Agency (EPA) announced their intent to regulate mercury emissions from the nation's coal-fired power plants. The decision was based on the risks associated with current emission levels and potential buildups of methylmercury in lakes and rivers. There will be a three-year period to develop proposed rules, followed by one year to finalize the regulation, with full compliance required in 2007.

In anticipation of potential regulations, a great deal of research has been conducted during the past decade to characterize the emission and control of mercury compounds from the combustion of coal. Much of this research was funded by the Department of Energy, EPA, and EPRI and results are summarized in the comprehensive AWMA Critical Review Article[1]. As a result of these efforts, the following was determined:

1. trace concentrations of mercury in flue gas can be measured relatively accurately;
2. mercury is emitted in a variety of forms;
3. mercury species vary with fuel source and combustion conditions; and
4. control of mercury from utility boilers will both difficult and expensive.

This latter point is one of the most important and dramatic findings from the research conducted to date. Initial estimates of emission costs were based on the experience gained from waste combustors in which mercury can be captured for a few hundred dollars per pound. However, because of the large volumes of gas to be treated, low concentrations of mercury, and presence of difficult to capture species such as elemental mercury, some estimates show that 90% mercury reduction for utilities could cost as much as $5 billion per year[1]. Most of these costs will be borne by power plants that burn low-sulfur coal and do not have wet scrubbers as part of the air pollution equipment.

With regulations rapidly approaching, it is important to concentrate efforts on the most mature retrofit control technologies. Injection of dry sorbents such as powdered activated carbon (PAC) into the flue gas and further collection of the sorbent by conventional particulate control devices (electrostatic precipitators (ESPs) and fabric filters) represent the most mature and potentially most cost-effective control technology for utilities. However, all of the work to date has been conducted using bench-scale and pilot experiments. Although these reduced-scale programs provide valuable insight into many important issues, they cannot fully account for impacts of additional control technology on plant-wide equipment.

Therefore, it is necessary to scale-up the technology and perform full-scale field tests to document actual performance levels and determine accurate cost information. Under a DOE/NETL cooperative agreement, ADA-ES is working in partnership with PG&E National Energy Group, Wisconsin Electric, a subsidiary of Wisconsin Energy Corp., Alabama Power Company, a subsidiary of Southern Company, and EPRI on a field evaluation program of sorbents injection upstream of existing particulate control devices for mercury control[2]. This program is specific to units that do not have scrubbers for SO_2 control or hot-side ESPs. Organizations participating in this program as team members include EPRI, Apogee Scientific, URS Radian, Energy & Environmental Strategies, Physical Sciences, Inc., Microbeam Technologies, EERC, EEC, Hamon Research-Cottrell, Norit Americas, and EnviroCare.

The objectives of this multifaceted program are to:

1. accelerate the scale-up and availability of commercial mercury control systems for coal-fired plants;
2. obtain data on operability, maintainability, and reliability;
3. determine the maximum mercury removal for various plant configurations; and
4. determine the total costs associated with mercury control as a function of fuel and plant characteristics.

Testing will be conducted at four sites, shown below, that burn coal and have particulate control equipment that are representative of 75% of coal-fired generation.

Test Site	**Coal**	**Particulate Control**
PG&E NEG Salem Harbor	Low S. Bituminous	Cold Side ESP
PG&E NEG Brayton Point	Low S. Bituminous	Cold Side ESP
WEPCO Pleasant Prairie	PRB	Cold Side ESP
Alabama Power Gaston	Low S. Bituminous	Hot Side ESP COHPAC FF

One task in this program is to perform an integrated analysis of data gathered from the four sites with results from other test programs being conducted by EPRI and DOE and data collected in Phase III of the ICR. Key variables will be identified and their effect on mercury removal with and without dry sorbent injection will be quantified. This paper presents a summary of the initial efforts with the data integration.

REVIEW AND COMPILATION OF AVAILABLE DATA

Overall ICR Data Review

Phase III of EPA's Information Collection Request (ICR) identified a statistical sampling of plants for stack and waste measurements. Mercury was measured across the control devices using the modified Ontario Hydro method for total and speciated mercury. Analysis of the data by EPA, EPRI and others show general trends (for all coal types, boiler types, and emissions control configurations) that include[3]:

- Coal type and properties affect mercury speciation.
- Oxidized mercury (Hg II) is easier to absorb than elemental mercury (Hg^0)
- Ability to capture mercury increases with decreasing temperature.
- Absorption of mercury onto fly ash is thought to be related to fly ash carbon content.

Review of Mercury Data Relating to Non-Scrubbed, Cold-Side Units

Most of the reviews of the ICR data that have been published provide an overall interpretation of the data, including all configurations (coal types, boiler types, and emission control equipment). In this program it is of interest to analyze mercury capture in non-scrubbed units with ESPs or fabric filters for each of the major coal categories: bituminous, subbituminous and lignite. The analysis does not include units with fluidized bed combustors. In addition to the ICR data, the author's have collected data for mercury removal across full-scale ESPs and fabric filters from published EPRI and DOE reports to include in the database. The plant specific data was supplemented with parameters that contribute to mercury capture which have been identified during lab and pilot-scale studies conducted during the past ten years. These factors include:

- the effect of temperature on mercury capture with fly ash for some fly ash types[1],
  - lower temperature may increase the mercury capture both across the particulate collector and across a sampling filter (sampling artifact)
- the potential impact of fly ash on a sampling filter on measured mercury removal and oxidation
  - fly ash captured on the sampling filter may alter the measured vapor phase mercury (mercury removal by the fly ash) and oxidized/elemental ratio (mercury oxidation by the fly ash)
- the difficulty of transporting mercuric chloride (reacts/"sticks" to fly ash, tubing, etc.)
- the difference in mercury removal capabilities between a fabric filter, where a dustcake is present, and an ESP
- the impact of dustcake thickness and cleaning frequency on mercury removal in a fabric filter
  - pressure drop and cleaning frequency were not included in most ICR reports
- the effect of LOI carbon on mercury removal
  - LOI was not included in most ICR reports
- the importance of sorbent size distribution for overall mercury removal
  - LOI in fly ash may be important but size distribution of the carbon may also be a critical parameter
- the influence of residence time on mercury removal
  - units with long duct runs or large ESPs may have more mercury removal

A thorough review of the available full-scale data was conducted with special attention to factors that could contribute to mercury removal as defined by the trends observed in laboratory and field research. For example, data collected at the inlet to the particulate collector are assumed to represent an accurate measure of the total mercury present at that location. However, since some fly ash can remove and/or oxidize mercury, the mercury speciation measured at the inlet to the particulate collector does not necessarily accurately represent the speciation in the duct at that location. Also, mercury collected on the sampling filter with the fly ash is considered to represent the affinity of the specific fly ash to mercury but not necessarily the amount of mercury on the particulate at that location in the system. In other words, the mercury may have been captured on the fly ash as the gas sample passed through the sampling filter.

To minimize discrepancies in the data, all mercury data from the draft Ontario Hydro tests were recorded from reports as micrograms of mercury collected in the specific impinger or particulate catch, to the total gas volume collected during the sample. Errors were noted in the summary sections of some ICR reports that resulted when converting the measured mercury concentration in $\mu g/m^3$ to lb/Tbtu. This error sometimes occurred when a portion of the flow at a unit was measured at one location (i.e. A or B-side) and compared to the combined flow at the other location. For each test, the volume collected for the sample was recorded as dry normal cubic meters corrected to 3% oxygen. Normal conditions for this paper are considered to be at a pressure of 29.92 inches Hg and a temperature of 68 ^oF. This definition was not consistent for all test contractors. Also, in some reports, the mercury concentrations presented in the test summary were corrected to 3% O_2 and others were reported as measured. For this paper, all concentrations were corrected to 3% O_2 to account for any air inleakage across the particulate collector that may contribute to an apparent mercury removal caused by a dilution of the gas.

The temperature of the sampling filter was also included in the database evaluated during this program to determine any correlation in the fraction of mercury collected on the sampling filter and the temperature of the filter. Other data included in the database were the SCA of the ESP[4], the type of fabric filter tested and average pressure drop across the filter if reported, and the estimated LOI carbon in the ash for the unit. The LOI values were obtained from plant engineers when possible and from combustion experts familiar with the plant when a direct value was not available.

Data Integration

The goal of this effort is to integrate available mercury measurement from full-scale units with results from the full-scale evaluations of PAC injection for mercury control to predict mercury removal and costs for a broad range of plants. However, as will be shown in the next section, the preliminary analysis conducted to-date for this program shows that general trends found in more comprehensive studies may not be applicable within a specific coal type. In addition, the limited data set available prevents a thorough survey of significant contributors to mercury removal.

During the current DOE program, baseline tests (no sorbent injection) will be conducted to better understand several factors that may affect mercury removal. These data will be added to the current database to better predict removal for units with ESPs and fabric filters. Tests have been planned to isolate likely contributors to removal and evaluate their specific effects. These contributors and the tests planned include:

- Duct temperature with PRB and bituminous fly ash
  - Modify duct temperature by spray cooling or adjusting plant operation
- LOI in bituminous fly ash
  - Adjust combustion characteristics to vary LOI
- Effect of SNCR
  - Turn urea injection on and off during semi-continuous mercury sampling

- Effect of residence time for in-flight mercury removal by particulate
  - Measure vapor-phase mercury at various points on a long duct run downstream of the air preheater
- Effect of SO_3 on mercury removal on PRB and bituminous fly ash
  - Adjust the amount of SO_3 injected with a SO_3 conditioning system

DATA INTERPRETATION AND MERCURY REMOVAL TRENDS

The parameters that the authors chose to focus on in this analysis are:

- Percent of mercury measured on the inlet filter of the modified Ontario Hydro test and the temperature of the filter during testing as in indication of removal across the ESP or FF
- Inlet temperature
- Coal chloride concentration
- Specific Collection Area (SCA) of the ESP
- Carbon in the fly ash (LOI)
- Flue gas conditioning

Table 1 presents a summary of data from 19 units that have cold-side ESPs as the primary particulate control device. The majority of data in this table were taken from the ICR tests. Additional data were obtained from plants where either Ontario Hydro or R&D funded mercury measurements were made[5]. Specific names of plants are omitted at the request of some of the contributors. The data are organized by coal type with 7 units on bituminous coal, 4 units on lignite, 5 units on subbituminous, and 3 units firing a mix of bituminous, subbituminous and/or pet coke.

Similarly, Table 2 presents data from 10 units with fabric filters. This data set has 4 units on bituminous, 1 unit on lignite, 3 units on subbituminous and 1 unit with a mix of coals. No COHPAC units were included in this data set.

The first comparison is the average mercury removal by subset group. These data are presented in Table 3. Data from Tables 1 and 2 that are negative for mercury removal are considered to have 0% removal. These data show that without additional sorbent injection, fabric filters have 70 to 84% mercury removal on bituminous and subbituminous coals. ESPs have removal efficiencies slightly lower than fabric filters, 66%, when a mixture of coals that include a bituminous is fired. Both ESPs and fabric filters have very poor removal on lignite coals, however all lignite units included in the analysis were operated at fairly high temperatures (330 – 395^{o}F). ESPs have poor mercury removal with subbituminous coals (290-322^{o}F).

Table 1. Non-Scrubbed Units with Cold-Side ESPs

ID*	NOx Control	FGC	SCA ft^2/Kacf	ESP Inlet Temp ^oF	Coal Chloride ppm	Ash LOI %	Hg on Filter %	Hg Removal %
B-1	LNB		290	289	882		0	8
B-2	LNB		550	310	575	5-10	36	26
B-3	LNB		550	245	966	3-7	30	23
B-4	LNB		252	322	2100	5-10	29	24
B-5	LNB		346	321	800	5-10	75	30
B-6	LNB&S NCR		475	262	264	25	84	88
B-7			323	320	333	3-6	60	46
B-8	LNB		440$^+$	338	3620	<1	82	74
L-1	LNB		599	368	18		0	7
L-2			267	395	115	1.4	17	-2
L-3				368	29		5	-1
L-4	LNB		470	329	74	1-5	1	-4
S-1		SO_3	468	291	100	<.5	2	-35
S-2	OFA	SO_3	686	306	57	0.09-0.18	1	-3
S-3	CC		213	317	133	1-2	16	10
S-4	LNB		279	322	76	1-2	0	8
S-5		SO_3	279					28
Mix-1			220	342	180	10-20	84	67
Mix-2			220	308	187	10-20	77	54

*B = bituminous, S = subbituminous, L = lignite, mix = blend

$^+$ Unit also has out-of-service cold side ESP upstream of current ESP (longer residence time)

Table 2. Non-Scrubbed Units with Fabric Filters as Primary Particulate Collector

ID*	NOx Control	FF Inlet Temp ^oF	Coal Chloride ppm	Ash LOI %	Hg on Filter %	Hg Removal %
B-1	LNB	340	167	10-20	76	51
B-2	LNB	299	55		80	87
B-3	LNB	307	1233		100	100
B-4	LNB	290				99
L-1		358	167	2-4	14	-21
S-1	LNB	348	100	2-4	36	82
S-2	OFA	293	<10	1-2	16	57
S-3	LNB, OFA	342		<1		72
Mix-1	LNB	314	127	20-25	2	-4

*B = bituminous, S = subbituminous, L = lignite, mix = blend

Table 3. Summary of Average Mercury Removal in ESPs and Fabric Filters

Coal	ESPs (% Hg Removal)	Fabric Filters (% Hg Removal)
Bituminous	35	84
Subbituminous	9	70
Lignite	2	0
Bit/Sub/Pet Coke Mix	66	NA

Statistical analyses using the Pearson Product-Moment correlation were performed with respect to the primary variables of interest identified above, for each subset group with more than 3 units. The Pearson Product-Moment correlation between two variables reflects the degree of linear relationship between two variables, ranging from +1 to -1. A correlation of +1 means that there is a perfect positive linear relationship between variables and a correlation of –1 indicates a perfect inverse linear relationship. A correlation of 0 means there is no linear relationship between the two variables.

Table 4. Correlation with Mercury Removal (3% O_2)

	ESP			**FF***
	Bit	**Sub**	**Lig**	**Bit**
SCA (ft^2/1000cfm)	0.25	-0.91	0.80	NA
Inlet T (^oF)	-0.26	0.85	0.07	-0.39
Coal Chloride (mg/g)	-.52	0.55	-0.61	0.57
LOI (%)	0.84	0.97	NA	NA
Hg on Sampling filter (%)	0.81	0.63	-0.49	0.95

* Data included for categories with 4 or more data points (plants)

A summary of the analysis of several potential factors influencing mercury removal is presented in Table 4. The amount of mercury captured on the sampling filter at the inlet of the particulate collector is also included on this table. Trends, when choosing a value greater than 0.7 as significant, show:

- Mercury measured on the sampling filter of the Ontario Hydro test provides a good indication of mercury removal across the ESP or fabric filter for bituminous coals.
- Increased carbon in the fly ash correlates with higher mercury removal in ESPs for bituminous and subbituminous coals.

- There is a correlation between higher temperature and higher mercury removal with the subbituminous coals in ESPs, but this correlation is highly unlikely. There is a narrow data spread (0 to 10% removal at 291 to 322°F) for this particular analysis.
- The size of the ESP, SCA, correlates with higher mercury removal in ESPs on lignite coals. Although this correlation appears to be significant, the highest level of mercury removal in this subset was 7%. For subbituminous coals, there appears to be an inverse correlation between SCA and mercury removal (the smaller the SCA, the higher the removal). It is expected that other factors are contributing because it is unlikely that this is a true correlation.
- No significant correlation with coal chloride level was found for any of the coal type subsets. However, the units burning bituminous coals have higher coal chloride on average and also have higher mercury removal on average.
- Flue gas conditioning with SO_3 was used on 3 of the 5 ESPs burning subbituminous coals. The use of SO_3 conditioning did not appear to influence mercury removal.
- No significant correlations with LOI, coal chloride or temperature were noted across the fabric filters.

A more detailed examination of the data available for the fabric filters suggests some additional trends. These trends are presented on Figure 1. For most of the plants burning bituminous coal, the mercury removal was fairly consistent until the temperature of the fabric filter outlet exceeded 305 °F. The fabric filter on the plant that burned the blended coal showed virtually no mercury removal (temperature at the outlet was greater than 315 °F). For this particular plant, it is unlikely that operating at a slightly lower temperature would result in improved mercury removal because the inlet sampling filter, which was maintained near 230°F for these tests, captured a maximum of 2.8% of the incoming mercury. This indicates that the ash has a very low affinity for mercury.

For the units burning subbituminous coals, good mercury removal was achieved at temperatures over 330 °F. This suggests that the collection mechanism for subbituminous fly ash is not as dependent on temperature as the bituminous fly ash. Since the subbituminous coals produce primarily elemental mercury, this data may indicate that the reactivity of elemental mercury may not be as dependent on temperature as oxidized mercury.

The lignite site presents some very interesting results. The fabric filter outlet temperature at this site was nominally 330 °F for all three test runs. The mercury removal ranged from –51% to +28%. In addition, the highest fraction of mercury captured on the inlet sampling filter during testing at this site was 34%. The filter temperature during these tests was 260°F. These two sets of data (the mercury removal across the fabric filter and the mercury capture on the sampling filter) suggest that the ash has an affinity for mercury at lower temperatures. However, at the fabric filter operating temperature, very small changes in temperature can account for either adsorption onto the filter dustcake, or desorption of mercury back into the flue gas.

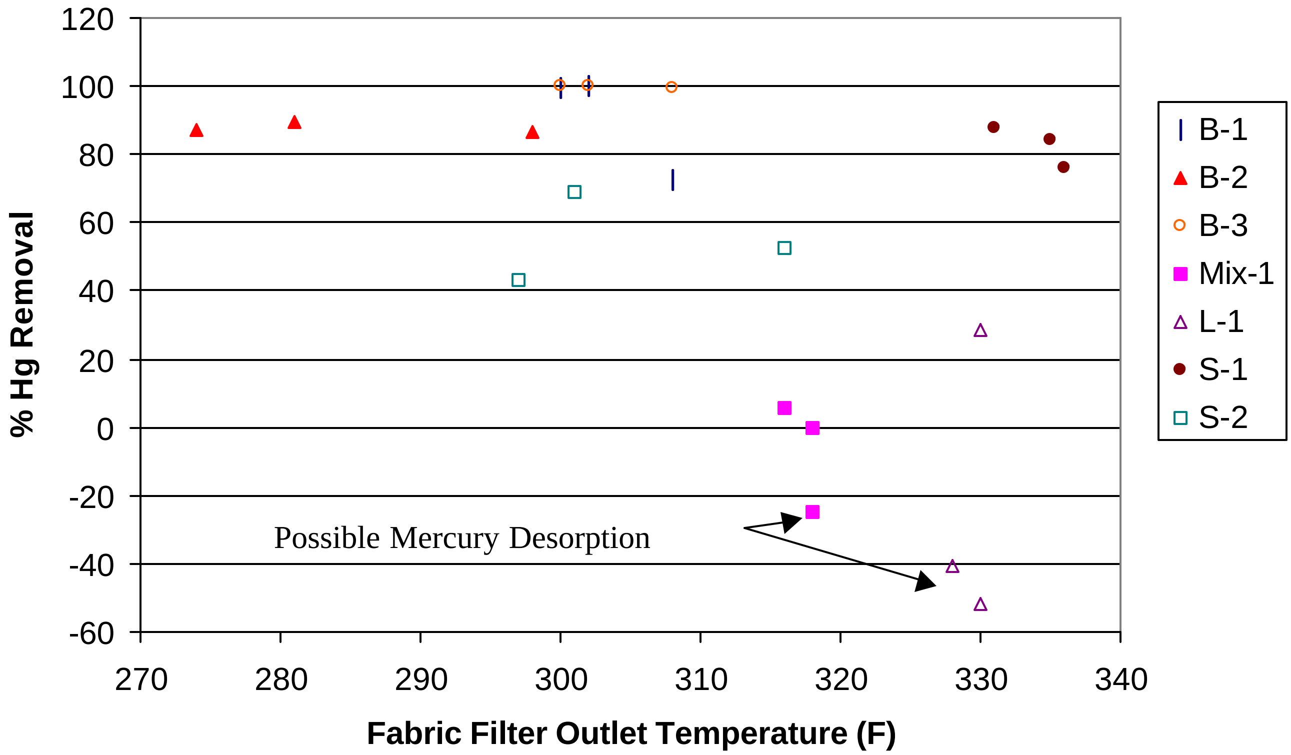

Figure 1. Mercury Removal Across Fabric Filters

CONCLUSIONS

Review of available data from full-scale coal-fired power generation facilities with cold-side ESPs and fabric filters suggest several important factors that influence mercury removal. These factors are listed below. There are other factors believed to contribute to mercury removal and many of these will be characterized during the next year under this DOE program. Understanding parameters that influence mercury removal and characterizing the impact of sorbent injection on mercury removal will provide a method for plants to maximize baseline mercury removal and project costs for additional mercury removal with sorbent injection. Mercury removal trends identified thus far include:

ESPs:

Subbituminous Coal

Mercury measurements showed poor mercury removal (average 9%) across particulate control devices with subbituminous coals. Increased LOI carbon correlates with higher mercury removal.

Lignite Coal

Very poor mercury removal (average 2% at temperatures above 330^{o}F) was measured on units firing lignite coal.

Bituminous Coal

Fair mercury removal (average 35%) was measured at temperatures below 325^{o}F. Increased LOI carbon correlates with higher mercury removal.

Mixed Coals

Good mercury removal (average 61% at 308 – 338^{o}F) was seen on units firing a blend of coals.

Fabric Filters:

Bituminous and Subbituminous Coals

Good mercury removal (average removal 84 and 70%) was measured at temperatures below 310^{o}F.

Lignite Coal

Poor mercury removal (average 0%) was measured on units with temperatures near 330^{o}F. Based on mercury captured on the sampling filter (max 34% at 260^{o}F), it is possible this ash will remove some mercury at lower temperatures.

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